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[*Special Supplement to Vol. XIV of Proc. of Birm. Nat. Hist. and Phil. Soc.*, 1921.]

The Geological Work of Charles Lapworth,

M.Sc., LL.D., F.R.S., F.G.S.

Professor of Geology and Physiography
at the University of Birmingham.

By
W. W. WATTS.

Price — Two Shillings.

The Birmingham Printers, Ltd., 42-44, Hill Street

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Addl.

THE GEOLOGICAL WORK

OF

CHARLES LAPWORTH, M.Sc., LL.D., F.R.S., F.G.S.

I.—LIFE.

CHARLES LAPWORTH was born on September 20th, 1842, at Faringdon, in Berkshire. Five years afterwards his parents removed to Lower Newton, one of the farms rented by his grandfather. He attended the country school of Buckland, about two miles off, and the Vicar of the parish, the Rev. Joseph Moore, finding him an omnivorous reader, lent him books from the library of his beautiful house and practically directed his early education. His mother's influence supported him in his determination to devote himself to the profession of teaching. At the age of 15 he became a pupil teacher in the school, and in the year 1862 entered the Training College at Culham, near Oxford, passing out thence in 1864 with a first-class Government certificate. Of the posts as schoolmaster offered to him he selected that connected with the Episcopal Church at Galashiels, because it would give him a home and work in the fascinating borderland of Sir Walter Scott. This post he retained for eleven years, and was married in 1869 to the daughter of Mr. Walter Sanderson, who survives him, and to whose lifelong devotion and thoughtful care he owed much that rendered his work possible.

His holidays and spare time were spent in wandering over the Border region, and about 1866 or 1867 he appears to have become interested in geology, zest being given to the work by the discovery of fossils in rocks which had hitherto been considered barren. In 1869, in company with his friend, Mr. James Wilson, he began the study of the geology of the district round Galashiels. As his work became known he was visited by many eminent geologists, among whom may be named Sir William Dawson, Mr. Hopkinson, Professor Harkness, and Professor Nicholson, with whom he formed a life-long friendship.

In 1875 he was appointed to one of the assistant-masterships in the Madras College, St. Andrews. While here he not only continued his study of the Scottish Uplands, but found time to visit localities in England and Wales of importance to his work.

He was elected a Fellow of the Geological Society in 1872, and received the Murchison Fund in 1878, a few months after the reading of his great paper on the Moffat Series.

In 1881 he was elected to the newly established Chair of Geology and Mineralogy at the Mason College, Birmingham, his title being afterwards modified at his own request to that of Professor of Geology and Physiography. Here he took part in the development of the College which resulted in the establishment of the University of Birmingham in 1900, received the official degree of M.Sc., and held the Professorship till his retirement in 1913. The University conferred on him the title of Emeritus Professor in 1914.

In 1882, and again in 1884, he was awarded the Lyell Fund, and in 1887 the very distinguished honour of the Bigsby Medal, by the Geological Society. On the occasion of the presentation of this medal the President, Professor J. W. Judd, remarked:— "The late Dr. Bigsby established a medal to be awarded to one 'not too old for further work, and not too young to have done much.' That you admirably comply with the latter qualification every geologist knows, but that your age could possibly fall below the limit prescribed by the founder of the medal, anyone not personally acquainted with you might be pardoned for doubting."

Aberdeen University created him LL.D. in 1884, and in 1888 he was elected a Fellow of the Royal Society, which awarded him a Royal Medal in 1891 and placed him on the Council in 1895. In 1892 he served as President of the Geological Section of the British Association. He went on to the Council of the Geological Society in 1894; in 1899 received the highest award of that Society, the Wollaston Medal; and in 1902 became its President. In 1900 he served on the Departmental Committee on the Geological Survey, and from 1902 to 1905 on the Royal Commission on Coal Supplies. In 1905 he received the Wilde Medal of the Manchester Philosophical Society, and in 1912 was made honorary LL.D. of the University of Glasgow.

After an illness lasting several months he died on March 13th, 1920, in his 78th year, and was buried by his own desire at the Lodge Hill Cemetery, near Birmingham.

II.—WORK.

Introduction.

In order to understand rightly, and to place Professor Lapworth's geological work, or at least the first part of it, it is necessary to appreciate the level which knowledge had reached at the time his work began.

The geology of the greater part of England and a considerable part of Scotland had been mapped and described. The Geological Society had been publishing for sixty years, and several other societies and journals were making known the results of geological investigation. The series of rocks down to the base of the Carboniferous were fairly understood and consistently mapped, their succession and faunas were known in outline, and correlation was in a fairly satisfactory state. In some cases at home and abroad detailed zoning of the strata had been carried out.

But the knowledge of the older Palæozoic rocks, in spite of the labours of Sedgwick, Murchison, Hicks, Harkness, Nicholson, and many others, was in a much less satisfactory condition. Neither subdivision and correlation, nor mapping, was reliable, and there remained much to be done in the collection of the faunas in an accurate, detailed fashion. Trilobites and brachiopods had been mainly used for correlation, but had led to contradictions and inconsistencies. The graptolites, which Lapworth was to make so important, were almost neglected, and even their keenest students—Nicholson, Carruthers, and Hopkinson—had not full confidence in their value. Nor even was the classification of them then in use the best possible, for it was founded on imperfect and imperfectly known specimens, leading to uncertainty and indefiniteness in the identification of species, and even of genera and families.

A.—The Southern Uplands.

The Southern Uplands, in the centre of which, at Galashiels, Lapworth settled down from 1864 till 1875, was known to be made up of rocks of greywacke type, somewhat similar to those of the Lake District and Wales, but singularly barren of fossils. They were known to dip steadily, but not very regularly, from south to

north, off a supposed anticline near Hawick, and were considered to constitute a single ascending series not less than five miles (26,000 feet) thick. At intervals there occurred bands of black shale, never more than five or six hundred feet thick, which seemed to be part of the conformable series. These shales yielded almost the only fossils, chiefly graptolites, and very little else.

Now the graptolites collected from one band as a whole were quite comparable with those found in every other band, and the fauna of the lowest band was not appreciably different from that of the highest. Many of these graptolites had been found in the Llandeilo rocks of Wales. These conclusions, if reliable, led inevitably to the following deductions :—

(1) As there was no change in fauna or lithological character the whole series must belong to one Formation.

(2) The recognised fossils were, or were thought to be, Llandeilo forms—hence that Formation would be the equivalent of the Llandeilo.

(3) As the same graptolites were found in every shale band throughout five miles of rock, the graptolites as a class were useless as time-indices.

(4) As 26,000 feet of rock had been deposited during the life time of the Llandeilo graptolites, either :—

(*a*) Deposition had been excessively rapid, although the greywackes include ten or twelve black shale bands deposited in deep water ; or

(*b*) The graptolites presented an example of a group of organisms which had stood still during the lapse of a long period of time. They were in contradiction to the theory of progress and evolution which was beginning to receive valuable support from geology, particularly in rocks of later ages.

From what we know of Lapworth's method of work we may feel sure that either before or very soon after beginning his field work he had got hold of all the published information on the Uplands, and that his logical mind would soon draw some such deductions as those outlined above.

Further, from his profound belief in well grounded scientific principles we may readily suppose that conclusions so much in conflict with what was then known in other branches of geological enquiry would be inacceptable, and that he would feel that the foundations on which they were supposed to rest must be tested with great care.

It is true Barrande had formulated his theory of ' colonies ' to explain similar anomalies in Bohemia, and that theory had been

invoked in the Uplands. But the theory was almost too ingenious and it involved a complicated series of migrations, the mechanism for which it was almost impossible to imagine.

Lapworth's field work showed bit by bit that the foundations on which such conclusions rested were unsound, and at the same time placed our knowledge of the Southern Uplands in a position of remarkable exactitude. It went further, and established a host of facts and a number of new principles which have proved to be far-ranging in application.

1.—Galashiels.

Lapworth's field work had probably begun in 1866, but as a serious study it dates from 1869, and reached the stage of first publication in 1870, when a paper on the Lower Silurian Rocks of Galashiels (1)* was read to the Edinburgh Geological Society. From this we gather that he had detected the intense disturbances which had affected the rocks. He had found many fossils in strata supposed to be barren and unpromising, and had begun to realise that these fossils would be of considerable assistance in his work. He had also seen that the Gala Series was a large and united Formation bearing similar monoprionidian graptolites from base to summit, very different from the more varied graptolite fauna of the black shales in the underlying Moffat Series. Many of the Moffat Shale graptolites are peculiar to the Llandeilo, others are found in the Coniston group; while the whole of the Gala forms have been found in the 'Coniston Series,' and in the Upper Silurian of Bohemia. From this he concluded that the Gala Series was of Caradoc age. This last view, though it has proved erroneous, was inevitable at this time, as the opinion held by Nicholson, and others who had worked on them, was that the 'Coniston Flags' belonged to this period. In a further paper (4) read at the British Association at Edinburgh, twenty Gala species are recorded, two being new to science.

2.—The Moffat Area.

A very important paper (2) by James Wilson and Lapworth, in 1871, records the result of three years' work. The great significance of the graptolites is now well recognised. The shales, the most important part of the Moffat series, are spoken of as the "metropolis of the graptolites of Scotland," and the authors feel bound to say, †"These peculiar creatures have never yet received the attention they deserve, and those of Britain have been treated so carelessly that the real horizon of some of the species cannot be even guessed at." Forty species of graptolites are recognised from the Moffat

* Figures in brackets refer to the list of published works set out on pages 49-51, in order of date. † 2, p. 463.

Shales, nine-tenths of which, including all the branching forms, have disappeared in the Gala group. Twelve species have been found in the Riccarton beds overlying the Gala Series. The Moffat Shales are compared with the Utica and Hudson River beds of America, and with the graptolitic shales of Wicklow and Wexford, and are thought to be of Bala or Bala-Llandeilo age. The Gala group has a fauna approaching that of the Coniston mudstones, and also Barrande's 'colonies' and stage E.e.1. of Bohemia. They seem to be high up in the Lower Silurian, and probably the higher beds are of Upper Silurian age. The authors demonstrate the existence of a syncline of Gala rocks with the Moffat Shale north and south of it, and that on each side the shale band is several times repeated by folding or faulting.

In a short paper (5) published in 1872, Lapworth categorically states that he has convinced himself that all the black shale bands are a single bed 500 to 600 feet thick, recurring again and again in anticlines between which the conformable Gala greywackes occur in repeated synclines. The black shales are divided into three stages—a Lower, parallel with the Llandeilo or Hudson River beds; a middle, like the Upper Llandeilo of Builth; and an Upper, supposed to be a Caradoc. Some of the groups are further divisible into zones which can be traced from point to point.

From this paper it is clear that Lapworth was now hard at work on the Moffat region itself. By this time also his studies had convinced him that the application of the simple rules and methods appropriate to little-disturbed rocks, to a region in which complicated structure might be concealed, would be highly dangerous and likely to lead to an utterly erroneous interpretation of the geology. He therefore set to work to map its 300 square miles in minute detail with the use of topographical maps on the largest scale he could obtain; and, where these were not large enough to record and depict the structures observed, surveying the ground and constructing his own maps on a sufficient scale.

At the same time he applied himself to the study of all the literature, English and foreign, on the graptolites, which he realised were the only organisms likely to afford him any assistance in identifying horizons in the monotonous black shale bands. He also visited other graptolite-localities, such as the Coniston and Stockdale areas, and studied graptolites collected by other geologists, such as those from Co. Down and St. Davids.

Further stages in his work are revealed in 1876, when he grouped together the Birkhill and Gala as one Formation, which he named Valentian (*) and compared with the Lower Llandovery, May Hill, and Tarannon Series. At this time he also effected tabular correlations of this and lower divisions.

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* 13, pp. 1, 2.

3.—**The Moffat Series** (16).

By 1877 he had exhausted his study of the facts in the Moffat district, completed his map, and prepared his memoir for submission to the Geological Society. It was published in the Quarterly Journal for 1878, and at once attracted the interest and sympathy of the younger men, but the incredulity and even hostility of holders of the older views.

In this memoir he confirmed the conclusions summarised above and, among others, established the following :—

(1) The thickness of rocks here is not abnormally great ; the appearance of thickness resulting from repetition due to inverted folding and faulting.

(2) Although the graptolite fauna of any one shale band as a whole is like that of any other, within each band there are a number of successive graptolite faunas, associated with variations in lithology, each distinct from the others.

(3) Within a single shale band two or more of these graptolite faunas are repeated, sometimes more than once. If in the repetition the faunas occurred in inverted order, evidence of overfolding could often be detected ; if the repetition was not in inverted order, evidence of faulting could usually be found.

(4) The graptolite faunas of a single shale band fall into three chief groups :—

  (*a*) A ' central ' (or lower) one, characterised by didymograptids and nemagraptids, of types known elsewhere in the Llandeilo series (Glenkiln Shales).

  (*b*) An ' intermediate ' (or middle) one, with dicellograptids and dicranograptids ; comparable with that of the Bala rocks elsewhere (Hartfell Shales).

  (*c*) An ' outer ' (or higher) fauna, with monograptids, comparable with those of the Coniston mudstones (Stockdale Shales) and other rocks of Silurian or Llandovery age (Birkhill Shales).

(5) He was able to divide the higher part of the shales into ten graptolite-bearing zones, four in the Hartfell and six in the Birkhill division.

(6) The rocks are not abnormally thick; indeed the whole of the history of the Upper Llandeilo, Bala, and Llandovery rocks is compressed into 200 or 300 feet of black shale, which must therefore have been deposited with comparative slowness, and, as the lithological characters of the shale show, in deep water, reached only by very fine sediment in small quantities.

(7) In spite of the great stratigraphical difficulties, rendered still more severe by the fact that the higher zones of the Birkhill Shales pass laterally, one by one, into greywacke undistinguishable from the greywacke above, as the strata are traced to the northward, we are given detailed measured sections showing the exact position, content, and extent of each division of the Moffat shales.

The result of this work, however, was not merely to rectify knowledge of the geology of the Southern Uplands. It rendered practically certain a number of inferences of world-wide application, which are not stated in the paper, those there set out being solely concerned with the area studied and the Moffat shale. To the reader is left the task and the pleasure of generalising from the results presented, and of realising how the foundations on which were based so many anomalies and contradictions to scientific principles, and so many obstacles to scientific progress, had crumbled away.

(1) It had become possible to zone the older Palæozoic rocks by the same methods as have been used in newer rocks.

(2) Graptolites are at least as valuable for zone-indices as ammonites and other forms.

(3) If patient and detailed mapping be based on it, such zoning may be used to unravel the most complicated structures.

(4) The Southern Uplands are proved to be a region which has suffered from complex earth-movements of the type found in great mountain regions.

(5) In such a region the old method of ' regional ' mapping, that is, the large-scale mapping of the greater lithological formations, is inapplicable, and must lead to wrong conclusions unless checked and supported by detailed work in which due weight is given to palæontological as well as to lithological evidence.

(6) So far from the evolution of the graptolites having stood still while thousands of feet of rock were deposited, the species and assemblages are found to change rapidly in each few successive feet of rock. Instead of controverting current theories of life-progress they give to them a new and firm support.

(7) Ingenious subterfuges such as Barrande's theory of ' colonies ' invented to explain anomalies in the geological distribution of organisms akin to those of the Southern Uplands, are untrustworthy and unnecessary.

It should be distinctly understood that this work was not carried out in the light of preconceived theory, nor was it possible for Lapworth to refer for guidance to a simple time-scale established elsewhere. It was the result of a belief in the efficacy of geological mapping, carried out with a minuteness and delicacy which had

never hitherto been attempted in a complicated district. But it was mapping executed by a man who was the keenest of observers, and who had by this time made himself perhaps the greatest master of the craft in the whole world.

Lapworth possessed a very sharp eye for lithological variation, and a vivid memory for lithological type. These he used in tracking the beds from point to point. At the same time he collected the graptolites from each bed as an additional means of recognising it, and as he acquired skill in their identification each group of graptolites became the ' hall-mark ' of its own bed. It was only when this dual means of recognition had unravelled the structure that the relations and sequence of the strata were revealed.

Thus the Southern Upland work was for the most part self-contained. Although, as has been already and will be again pointed out, Lapworth was at this time aware of all that had been done by others on the rocks and fossils of the Lower Palæozoic Group, and had himself begun to carry out work of comparison in many districts where knowledge was incomplete or inexact, this knowledge was not allowed to influence him in working out the detail of his own district, in forming any theories as to its structure, or in presenting his case to his compeers of the Geological Society.

The graptolites were used as symbols to help in unravelling the structure—the structure as it became known revealed the succession of the beds, and this, in its turn, disclosed the succession and relation of the faunas.

How welcome these results must have been to Lapworth we realise from his own words that *" zonal work is probably destined to effect in the history of geological research a revolution as great and an advance as rapid as those brought about by the use of the microscope in the history of biology."

It might have been expected that among scientific men such a vindication of scientific law would have received the warmest of welcomes. This, however, was not the case, for Barrande, whose theory of ' colonies ' had received its deathblow, declined to acknowledge defeat, and even named a newly discovered ' colony ' after Lapworth. Also in a work published a few years later we find the following footnote appended to a statement of the old views as to the Upland sequence :—

> " Mr. Charles Lapworth, who has devoted much time to the study of the graptolites of these rocks, has come to the conclusion that what is here termed the Moffat shale group, and regarded as merely a subordinate member of a thick series of sandy and generally unfossiliferous strata, represents the whole series of strata from the Llandeilo up into the

* 56, p. 520.

Upper Silurian formations ; that is to say, somewhere about a half of the whole Silurian system is contained in a group of shales and sandstones, sometimes less than 200 feet thick ! "

In a review of this work from Lapworth's pen we find the following retort :—*

" He parallels the famous colonies of Bohemia with the well-known fossil-bearing bands in the Silurian of South Scotland. We believe this comparison to be the best that could be made. In both areas the disputed successions are founded on corresponding appearances, and in both cases the belief in the orthodox view is probably destined soon to be confined solely to its authors. Both are, however, valuable warnings, with which the future student of historical geology could ill afford to dispense. One is the fruit of palæontology without stratigraphy—the other of stratigraphy without palæontology."

From 1888 onwards, however, some of the best geologists in the Scottish Geological Survey were engaged in re-examining and re-mapping the Southern Uplands and in testing the validity of the new views. In 1899 the Geological Survey published its great Memoir on the Geology of the Southern Uplands of Scotland, a work which has been described as a ' monument to the genius of the man who made it possible.' In this work, Dr. Horne, reviewing the history of research, writes as follows (pp. 24-25) :—

" In 1878 appeared Professor Lapworth's memoir on ' The Moffat Series ' in the Quarterly Journal of the Geological Society. The publication of this paper marks an epoch in the history of the Silurian Geology of the South of Scotland. It remains the greatest and most original contribution to the study of the life-sequence and structural relations of these highly convoluted rocks. For nearly ten years the author had devoted himself to the mapping of the various outcrops of the black shale series throughout the Southern Uplands. Selecting the Moffat district as a typical area where the sub-divisions of the series are admirably exposed, he unfolded in detail the structure of that interesting region. The paper is illustrated with maps and sections of the district extending from Annandale to St. Mary's Loch, and from the Vale of Ettrick to Hartfell. Taking Dobb's Linn and Craigmichan Scaurs as typical sections showing the sequence and palæontological features of the Moffat series, he demonstrates the true order of succession of the strata based on the vertical range of the graptolites. He describes the prominent parallel bands to the north and south of the

* 29, p. 83.

Moffat valley, and by means of confirmatory sections places his conclusions beyond all doubt. The various sub-divisions, lithological characters, and fossil zones are treated in great detail; a table showing the vertical distribution of the fossils is given, and the respective faunas of the three divisions of the Moffat series are compared with their foreign equivalents."

4.—**The Girvan Succession (26).**

In order to submit his Moffat conclusions to the severest test that he could devise, Lapworth now turned to the Girvan district, a region so difficult that, in spite of much field work by many observers, and of the extensive Gray collection of fossils, *" Professor Ramsay . . . . unable to reconcile the numberless discrepancies between the apparent sequence, palæontological and stratigraphical, as here developed and that worked out by himself in the regions of Siluria, has been driven to the conclusion that these Scottish rocks belong to an episode of a date between that of the Bala and the Llandovery, unrepresented among the fossil-bearing rocks of the South of Britain." " If,"† Lapworth proceeds, " the asserted heterogeneous intermixture of fossil assemblages of all types, elsewhere characteristic of distinct horizons, were actually found to obtain amongst them, palæontology might well abandon her claim to be the unfailing handmaid of stratigraphy among the more ancient formations. If, on the other hand, the cautious study of these deposits led to the demonstration of the contrary opinion—*i.e.*, that their distinct fossil assemblages were restricted, as in other lands, to different stratigraphical zones, British geologists would feel justified in attempting the correlation of their own Lower Palæozoic subformations with their nearest representatives all over the world."

Work had apparently been begun in the Girvan district before 1876, but Lapworth now resolved to attack this ground with the same exhaustive thoroughness as he had evinced at Moffat. He naturally employed the same methods as before, the individualisation of mappable bands, detailed stratigraphy and mapping, zonal collection, and especial attention to the faunas of bands in which he discovered graptolites. As the result he worked out a complete succession of strata beginning with the Lower Llandeilo or Arenig and ranging up into the Tarannon beds. The graptolitic bands followed one another in the same sequence as those of Moffat. Not all of them, however, were represented here, and between and among them were strata bearing brachiopods, trilobites, and other fossils which could—with some reservations—be compared

* 26, p. 541.

† 26, pp. 542-543.

fairly accurately with those found in rock successions of the same range in Wales and England.

As before, he contented himself with publishing the facts he had collected, denying himself even the satisfaction of correlation with Moffat, leaving it to be inferred by those sufficiently interested to compare the two papers, from the facts brought forward, (1) that the succession of graptolites was the same; (2) that, though the rock-succession was about ten times thicker than at Moffat, the rock-grouping corresponded in the two areas; (3) that many zones in one area were continued into the other; (4) that for correlation with other regions the graptolites of Moffat and Girvan had proved successful where the trilobites and brachiopods of Girvan had previously broken down.

*" The discovery of these graptolite zones in the Girvan area threw a flood of light on the stratigraphical horizons of that complicated region. He was thus enabled to demonstrate that Murchison had been misled by the apparent synclinal arrangement of the strata on the plateau on the south side of the Girvan valley, and that he had thus erred in placing the *Pentamerus* grits of Saugh Hill on a lower horizon than the graptolitic flagstones of Ardwell and Penwhapple Glen (Ardmillan series). Over much of that region the beds are inverted and hence no reliable conclusions can be based on mere superposition."

As this paper was called Part I, it is to be presumed that Lapworth intended to follow it up with a sequel devoted to the palæontology founded on his own and Mrs. Gray's collections, and probably also to the tectonics of the area, and the correlation of the rocks with those at home and abroad. The nearest approach to the former was his list of Scottish fossils prepared in 1876 for the meeting of the British Association at Glasgow. For the latter we have his paper on 'the Ballantrae Rocks of South Scotland,'† published in 1889 (44).

5.—The Ballantrae Rocks (44).

In this memoir Lapworth not only described his work on the Ballantrae igneous rocks—associated with which he had found graptolite-bearing strata of Arenig and early Llandeilo ages—but he gave detailed comparisons of the sequences in various parts of South Scotland. To this he added tabular correlations with the Lake District, Wales, and the West of England, drawing parallels with the zones so far established in each area, and giving a generalised account of the variations in lithology and thickness as the rocks are traced from one locality to another.

---

* The Silurian Rocks of Britain, vol. 1, Scotland (1899), p. 30.

† 44.

The Southern Upland rocks are divided into a 'Moffat Terrane' below, with its three divisions, Glenkiln, Hartfell, and Birkhill; and a 'Gala Terrane' above. The Moffat terrane at its maximum at Girvan is about 4,000 feet thick, but it dwindles to 300 or 400 feet about Moffat, and is only slightly thicker when it reappears at the surface in Lakeland. The Gala terrane, 2,500 feet at Girvan, at first thickens to the east and south-east, but it is much attenuated in the Browgill or Pale Slates of the Lake Country.

These points are shown in a series of magnificent sections across the Southern Uplands, which demonstrate clearly the Author's wonderful grasp of the complicated tectonics of the area, complications of such a nature and intensity that without detailed mapping the anticlines would be (and indeed had been) mistaken for synclines and *vice versa*, and the succession read in inverted order. The leading features are a great 'endocline' (pseudo-syncline or 'fan structure') ranging from Port Patrick through Carsphairn and Lead Hills, the Moorfoot and Lammermuir Hills, to Dunbar; and a great exocline (pseudo-anticline or reversed 'fan structure') from the Mull of Galloway, past Dumfries and Hawick, to St. Abb's Head. Roughly parallel to these are three complex anticlinal forms: (1) the Moffat-Melrose band; (2) the Leadhills-Moorfoot band; (3) the western zones of Ballantrae and Girvan. In the first band the rocks of the Moffat terrane show only as narrow inliers 'at the most a score or two of yards in width' in an area consisting of dominating Gala rocks. In the second band the exposures of the Moffat terrane are often more than a mile in diameter and are laid bare to a depth of 2,000 feet. In the third area the exposures of pre-Gala rocks are four or five miles across, and denudation has cut down to the underlying Ballantrae or Arenig rocks.

These sections, not published till 1889, which, though of course somewhat generalised, depict merely deductions from observed facts, show clearly the thorough understanding of intensely complicated mountain structure which Lapworth at this time possessed, and indeed must have acquired by the time of the close of his Upland field-work about 1881. It is most instructive to compare them with what he called hypothetical sections of exoclines and endoclines published in the 'Secret of the Highlands' in 1883. Nothing could better show on what a firm basis of fact, well known to himself, but often unpublished, his 'hypotheses' were always based.

Finally, he gives a summary of the knowledge so far arrived at by himself as to the general geological map of South Scotland; and a careful comparison of his last paragraphs with the latest results published by the Geological Survey of Scotland shows how little that knowledge deserves the depreciation he expresses.

6.—**Linnarsson.**

It was during the first decade of his scientific activity that Lapworth's friendship with Linnarsson, the great Swedish palæontologist, was formed, though I believe the two men never actually met. They, however, corresponded frequently and exchanged publications. Each seems to have told the other very frankly the work that he was doing and the results he was obtaining. As a consequence each one encouraged and aided the other; sequences worked out in Britain were tested in Sweden, the zonal work in the two countries proceeded simultaneously, and the case for graptolitic zoning grew ever stronger.

On two occasions Lapworth took the opportunity of bringing Linnarsson's work on the older Palæozoic rocks before English readers in the pages of the Geological Magazine, and he published at the same time a correlation table of the British equivalents of the Scandinavian subdivisions. Lapworth's admiration for Linnarsson was unbounded, and he has given very fine expression to it in his notices of Linnarsson's work and in the beautiful tribute on his untimely death in 1882.*

B.—The Ordovician System.

In 1879 Lapworth broke new ground, and rendered a very important service to the advance of geological science. His very extensive acquaintance with the literature of older Palæozoic geology, coupled with his own work on the rocks, had convinced him of the vital importance of the occurrence of three distinct and separate faunas in these rocks. Owing to misunderstandings, and to mistakes both stratigraphical and palæontological, this great issue was in danger of becoming obscured. It did not receive due recognition in the current nomenclature, the confusion of which was a terror to students and an impediment to scientific work and discussion (17).

Very tactfully and modestly, but very justly, he reviewed the history of the great Cambro-Silurian controversy, awarding to each disputant just as much credit as was due to him, in the words: †"We shall best promote the interest of the man whose memory we venerate by modestly claiming for him as much, and no more, than truth and geological convenience will allow." Then he suggested that we should ‡"claim the right of fully recognising the systematic equality of the three lower Palæozoic Faunas, by regarding the three successive rock-groups which contain them as individually entitled to the rank and denomination of a complete system." Finally, he proposed that if the lowest division of these

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* 20, 24, 27.

† 17, p. 12. ‡ 17, p 8.

rocks was to retain the name Cambrian from North Wales, and the highest that of Silurian from South Wales, it would be appropriate that the middle division should be named Ordovician from *" the last and most valiant of the old Cambrian tribes," whose geographical location was midway between the two areas. †" Every geologist will at last be driven to the same conclusion that Nature has distributed our lower Palæozoic rocks in three sub-equal systems, and that history, circumstance, and geologic convenience have so arranged matters that the title here proposed for the central system is the only one possible." It is quite needless to point out how completely this forecast has been verified.

C.—The North-West Highlands of Scotland.

For many years, as the science of petrology had been growing, doubt had been felt as to the correctness of conclusions founded on the apparent succession made out by Murchison in the North-West Highlands of Scotland. Here four great Systems of rocks—Lewisian (Laurentian), Cambrian (Torridonian), Lower Silurian (Assynt), and Higher Silurian (Eastern Gneiss)—were supposed to succeed one another in stratigraphical sequence, broken by two unconformities. The logical result of this reading of the succession was inevitably met by the grave difficulty that while the lowest and highest members of the sequence are crystalline gneisses and schists, the two middle members are at the most only very slightly metamorphosed, and indeed are generally ordinary sedimentary rocks still retaining clastic structures and well preserved fossils. Alternative explanations applicable to parts of the sections had been proposed by Nicol, Hicks, Callaway, Bonney, and Hudleston; but there was no comprehensive refutation of the basic error. Lapworth's experience of the mountain structures of the Uplands, with their deceptive appearance of normal sequence, suggested the possibility that here, too, the apparent simplicity might be a mere mask of intense complexity, and that rocks which had undergone so much chemical change were not likely to have escaped the violent earth movements which had produced such effects in the Southern Uplands. This presented a new problem really worthy of attack on account of the vital principles involved, and in 1882 Lapworth began his Highland work.

The Secret of the Highlands (30).

His method of attack was precisely that which had already led him to success. He saw that if his southern method were to be pursued the clue to the structure of the region would be found by him in the two middle series of sediments rather than in the complicated crystalline rocks.

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* 17, p. 14. † 17, p. 15.

He very soon discovered that while the broad rock sheets succeeded and were related to one another in apparent sequence, precisely as depicted by Murchison, individual parts of the section gave evidence of disturbance and even inversion. At the same time, well-weathered specimens of the rocks frequently displayed an astonishing contortion entirely incompatible with really simple relations of the greater bands.

Attention was then focussed on the third series, the "Lower Silurian," which Murchison thought to consist of three members, a Lower and an Upper Quartzite, with the Durness Limestone between. The first point was to ascertain exactly what the 'Lower Quartzite' consisted of, and to break it up into lithological or palæontological zones which could be mapped on the six inch, or, if necessary, on the 25 inch scale. The section made out by Lapworth was as follows:—

Under the Durness Limestone:

3. The Salterella (or serpulite) grit or quartzite.
2. The Fucoid beds (in three divisions)—
   - (*c*) Quartzose flags.
   - (*b*) Fucoid limestone.
   - (*a*) Fucoid zone (flaggy grey shales).
1. The Main Quartzite (in four divisions)—
   - (*d*) 'Pipe rock.'
   - (*c*) White quartzite.
   - (*b*) Tinted quartzite.
   - (*a*) Basal (conglomerate) zone.

The examination of the 'Upper Quartzite' showed that it invariably consisted of rocks exactly comparable with one or more of these lower quartzite types, *but of no others*. Further, that when more than one of the types existed the sequence of types was that found in the 'Lower Quartzite' either in normal or inverse order. Then he was able to trace out synclines of Durness Limestone beyond which beds comparable with some sub-division of the 'Lower Quartzite' succeeded; sometimes as though underlying the limestones and therefore older, at other times as though dipping away from it or overlying it and therefore newer. From this it became evident that the ordinary rules of simple stratigraphy led to two diametrically opposite conclusions as to the succession, and could therefore not be relied upon to give a correct solution. Finally it was found possible to start upon the 'Upper Quartzite' and, by walking along its outcrop without ever leaving it, to arrive on the outcrop of the 'Lower Quartzite.' Thus the view of Nicol that the 'Upper Quartzite' had no separate existence, but was merely the repetition of the 'Lower Quartzite,' was confirmed, and the complicated nature of the stratigraphy demonstrated.

The facts could only be accounted for if inversion due to folding or faulting had taken place.

Attention was next given to the Durness Limestone, and it is stated that it, *" though at first sight apparently homogeneous, of great thickness and of very gentle inclination, is actually made up of a few distinct lithological zones, repeated again and again in a series of faults or inverted folds."

Finally, he showed that the conglomeratic base of the quartzite rested with visible unconformity upon a ' crystalline rock,' which, though regarded by Nicol as an intrusive rock, was considered by Murchison, Heddle, and Callaway as " an integral part of the Upper [Eastern] Gneiss." Therefore rocks of ' Eastern type ' were in position unconformably under the quartzite, and the Eastern gneisses owed their apparently overlying position not to superposition but to disturbance.

The rest of this paper (' The Secret of the Highlands,' published in three parts in March, May, and August, 1883) is occupied with a discussion of the general and special principles of mountain structure as developed by Heim in his ' Mechanismus der Gebirgsbildung ' and illustrated with figures mainly taken from that work and from Favre's ' Recherches Géologiques.' In introducing this branch of his subject, the author remarks: †" Many of the points discussed in the following paragraphs will be found in the truly magnificent work of Professor Heim upon the convoluted rocks of the Alps. For those not hitherto published, I hold myself responsible. The latter therefore are the only points open to the objection of being original or heterodox, and the attempt here made to summarise a few of the more essential principles of mountain stratigraphy, and to apply them to the investigation of the Highland region may be, perhaps, received as a first essay on one of the most difficult and obscure departments of British geology."

The second part of this revolutionary work was destined never to be written. The hard work and harder living, coming on the top of his other duties, resulted in a serious illness from which he never really recovered sufficiently to regain the abounding health and vigour which had rendered possible the immense volume and depth of his earlier work. Before he had recovered health and leisure ‡" the whole force of the Geological Survey of Scotland laid siege to the Highland fortress " (as Professor Blake wrote in 1884).

The opportunity given, however, by the reading of Professor Blake's paper, just quoted, at the Geologists' Association in July, 1884, was accepted by Lapworth to communicate, at the suggestion of Mr. Teall, a few notes on some of the further results at which he

* 30, p. 124. † 30, p. 195.
‡ Proc. Geol. Assoc., vol. viii, 1883-4, p. 220.

had arrived before his work was broken off. These four or five pages are so rich in conclusions and suggestions that it is hardly fair to separate any portion from its context. The whole should be read in the light of 'The Secret of the Highlands.' The following quotations will show that Lapworth had followed the work to its logical issue as to the age and nature of the 'Eastern Schists,' and had also originated very definite views on the subject of dynamo-metamorphism (32).

*"The Sutherland Schistose series is composed of a complete intermixture of Archæan and Assynt rocks, the two series being so interfolded and interfelted together that they can never be separated in the field, but must be mapped simply as 'metamorphic.'

"If I can prove my case, we shall find :—†

(1) That there is no recognisable chronological sequence (or invariable succession of superposition) in the metamorphic Highland area corresponding to that among the sedimentary formations (for the planes dividing the truly metamorphic layers are not planes of deposition, but planes of shearing and cleavage).

(2) Many of its (the Highland) schists are composed of Archæan materials (rocks) which have received their present pseudo-bedded arrangement since Ordovician times.

(3) What proportion of its schists and gneisses is composed of Archæan, sedimentary, or intrusive materials respectively is in all probability an insoluble question.

(4) Its *gneisses* may be either Archæan or (some) possibly formed by intrusion (injection of plutonic rocks) in later stages.

(5) Its *schists* may be composed either of crushed *Archæans*, crushed *intrusives*, or of a mixture of these with sedimentaries.

(6) Its (so-called) *slates* may be (according to the locality, either normal slates or) crushed rocks not yet recrystallised, (and) of either Archæan, sedimentary, intrusive, or of mixed origin."

Some further details on the metamorphism of these rocks, which he regarded as having been directed if not caused by pressure, are given in a short paper read before the British Association in 1885, and published also in *Nature* of that year, while a summary of the question and an outline of the "Deformation Theory of Regional Metamorphism" was also published in Lapworth's edition of Page's 'Introductory Textbook of Geology,' which appeared in 1888 (pp. 106-118).

* 32, p. 438. † 32, pp. 441-2.

*" The most intense mechanical metamorphism occurs along the grand dislocation (thrust) planes, where the gneisses and pegmatites resting on those planes are crushed, dragged, and ground out into a finely laminated schist or *Mylonite* (Gr. *mylon* a mill) composed of shattered fragments of the original crystals of the rock set in a cement of secondary quartz, the lamination being defined by minute inosculating lines (fluxion lines) of kaolin or chloritic material and secondary crystals of a micaceous mineral."

†" The *mylonites* were formed along the thrust-planes, where the two superposed rock systems moved over each other as solid masses ; the *augen-schists* were probably formed in the more central parts of the moving system, where the all-surrounding weight and pressure forced the rock to yield somewhat like a plastic body."

The Geological Survey was close on Lapworth's track. Armed in 1883 with six-inch maps, half a dozen of their most competent Surveyors soon came into contact with the inexorable facts on which Lapworth's deductions were founded. In a report printed in *Nature* in November, 1884,† illustrated and considerably amplified on communication to the Geological Society in 1888, they not only confirmed the work that Lapworth had published, but in some instances advanced beyond anything he had published. Later still, in 1907, appeared the great Survey Memoir on the North-west of Scotland.

It was after the appearance of the report in *Nature* that Lapworth published a short note (33) entitled ' On the Close of the Highland Controversy,' in which he summed up the history and present position of the work in that region in a generous spirit and in masterly fashion. In this he states ‡" the conclusions at which I arrived seem to me to be identical in all their essentials with those recently published by Messrs. Peach and Horne " ; and again, referring to his " own results in so far as they affect the age, composition, and mode of formation of the eastern schists," *" The officers of the Survey reached their conclusions in complete ignorance of my results, and from a totally different direction." A mind not so great might conceivably have been tempted to express or feel it a hardship that he had not been given the opportunity of finishing his own work in his own way. Instead, he welcomes this complete confirmation and vindication of his work, warmly congratulates his rivals on their success, and—turns to other matters. I should like to quote, for the white light it throws on the character of the man, the whole of his closing paragraphs, but I limit myself to one of them. §" At the present time the several groups of students of these old rocks are all met together

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* 35, p. 1026.

† Nature, vol. xxxi, 1884-5, pp. 29-35, Quart. Journ. Geol. Soc., vol. xliv. (1888), pp 378—441. ‡ 33, p. 98. § 33, p. 102.

upon one and the same elevated platform of a common opinion, having climbed up painfully thereto from many different directions. The old subject of dispute has utterly disappeared, and there is no longer any reasonable excuse for dissension. We have all been partly right and partly wrong. It is a time for a hearty laugh all round, a time to shake hands and be friends."

D.—Geology of the Midlands.

The time had now come when his residence in Birmingham, on appointment to the Professorship at the Mason College, gave Lapworth the opportunity of turning to the study of the rocks of the Midlands. There is no local group on which he did not do useful work—from the Archæan to the Drift—but his chief interest lay naturally with the older rocks.

1.—Nuneaton and the Lickey Hills.

In the discussion at the Birmingham Natural History and Philosophical Society in 1882, upon a paper on the Drift Quartzites, by Mr. W. J. Harrison, Lapworth expressed the opinion, founded on work with Allport in October, 1881, that in all probability the Llandovery sandstones of the Lickey Hills would prove to be based unconformably on a quartzite similar to that known from Callaway's work at the Wrekin. Mr. F. T. S. Houghton supported this, basing his view on work done at Rubery some years previously. Early in March, 1882, Lapworth, in company with Professor M. J. M. Hill, obtained proof of the truth of his forecast, but he afterwards learnt that Houghton had seen the same facts and drawn a similar conclusion a little earlier.

A like suggestion as to the age of the Quartzites of Hartshill and Nuneaton was communicated by Lapworth to W. J. Harrison, when he found that the latter held similar views. The two worked the Nuneaton quarries together early in May, 1882, when they recognised the affinity of the Nuneaton to the Lickey quartzites and inferred that they were superior to the rocks of Caldecote. They also reached the conclusion that the overlying shales of Stockingford, believed to be and mapped as Carboniferous, were pre-Silurian. Lapworth confirmed this the following day by finding Cambrian fossils in them.

Later work, and mapping, often with classes of students, brought out the details of the Lickey area, enabled Lapworth to demonstrate the existence of pre-Cambrian igneous rocks under the (Cambrian) quartzite there, and further suggested to him the logical conclusion that the materials which constitute the Permian Breccias, and the fragments in the Bunter Pebble-beds, may not improbably have been derived from the ancient floor of Palæozoic

rocks lying hidden under the New Red Sandstones of the Midlands. This latter view he afterwards extended by showing that the Halesowen Conglomerates (Carboniferous) contained fragments denuded from the higher rocks of such an area, the Permian Conglomerates, fragments from beds lower down in the series, and the Permian Breccias, masses broken from the lowest rock-stumps, made of the oldest rocks left when denudation had cut down very deeply.

Simultaneously the Nuneaton work proceeded. The relation between the pre-Cambrian Caldecote rocks and the (Cambrian) Quartzites, at first inferred from conglomerates in the quartzites, was demonstrated in actual sections, the quartzite was sub-divided, beds of 'fucoid' type were found in it, middle as well as upper Cambrian fossils were discovered in the Stockingford Shales, the unconformable junction of the Carboniferous basement was revealed in open section, and at last the famous *Hyolithes* limestone with its fossils was discovered near the summit of the Quartzite, the discovery being based on observations communicated by Dr. T. Stacey Wilson in 1895, and announced in 1897.

2.—The Shropshire Ordovician.

This work, however, slowly developed itself between the years 1881 and 1897. Meanwhile he had other irons in the fire. He had already—before 1879—visited the Shelve district of Shropshire, but in 1885 he took up vigorously the work of mapping, and invited the writer to make a study of the igneous rocks of that district in his company. The first outcome of this work was communicated to the British Association at its meeting in Birmingham in 1886.* The stratigraphy turned out to be simple in comparison with that of South Scotland, and the succession proved to be complete from the base of the Arenig (Skiddavian) rocks to a level high up in the Bala (Caradocian). Many of the graptolite horizons established elsewhere were recognised, together with interbedded faunas of trilobites and shells. At the same time Lapworth took great interest in the igneous rocks, mapped them carefully, and made many valuable suggestions, several of which proved valid on the ground, as to the relations of these rocks to the sediments and as to their genetic relations among themselves. For example, from his preliminary work, and from his study of the Geological Survey map, he anticipated that the intrusive rocks would be laccolitic in form, as turned out to be the case.

He next extended his researches to the Caradoc country on the eastern side of the Longmynd, and soon satisfied himself that the main sedimentary series there rested unconformably on older

* 40.

rocks and consisted of representatives of the Bala Series only, which he was able to compare bed for bed with those of the Shelve district.

3.—The Shropshire Cambrian and Uriconian.

Naturally the fascinating rocks of Caer Caradoc and the Wrekin, and those immediately overlying them, claimed some attention. Callaway had described certain Shineton Shales as of Upper Cambrian age, and underlying sandstones, which he paralleled with the Hollybush Sandstone of Malvern, as probably earlier Upper Cambrian. Below this come quartzites which, on the balance of evidence, he thought likely to be pre-Cambrian. In a limestone in the Sandstone at Comley he found fossils, *" the most abundant being apparently trilobitic ; but it occurs in such a fragmentary condition, and is of such an unusual type, that I cannot express any opinion on its generic affinities."

To these fragmentary remains Lapworth devoted his attention. By the time the International Geological Congress met in London, in 1888, he had collected enough to convince him that he was in possession of a species of *Olenellus*, and when at the same Congress Walcott stated that the Americans had come into line with the Swedes in the opinion that *Olenellus* marked a Lower Cambrian horizon, Lapworth †announced his discovery, and a little later figured his fragments and constructed a restoration of the trilobite, which he named *Olenellus* (*Callavia*) *Callavei*.

Some of the consequences of this discovery were outlined in the earlier of these two papers, the leading conclusions being :—(1) the presence of a true Lower Cambrian fauna demonstrated for the first time in Britain ; (2) the existence of a new Cambrian rock-facies in England different from that of Wales ; (3) the practical certainty that the Uriconian rocks of the Wrekin, etc., are pre-Cambrian ; (4) the very high probability that the Longmyndian rocks are also pre-Cambrian ; and, if so, (5) the extreme likelihood that the Torridon Sandstone, so like the rocks of the Western Longmynd, would also prove to be pre-Cambrian.

Further discoveries followed : (1) That the Wrekin Quartzites, into which the sandstone containing the *Olenellus* limestone grades, are Lower Cambrian and not pre-Cambrian, a conclusion which carried with it the probability that the Lickey and Hartshill, and even the Durness, Quartzites were Cambrian too ; (2) the discovery by Dr. T. T. Groom of a species of *Paradoxides* in beds above the *Olenellus* Limestone proving the existence of Middle Cambrian beds in Shropshire, a conclusion amply verified by the subsequent discovery by Lapworth of a *Paradoxides* limestone

* Quart. Journ., Geol. Soc., vol. xxxiv. (1878), p. 759.
† 41, 46.

following the *Olenellus* Limestone at the Wrekin, and by the beautiful detailed work of Mr. Cobbold in the Comley area near Caradoc.

Lapworth directed the work of the fossil collectors for the Geological Survey and for Cambridge University, and large collections were obtained for these institutions from Cambrian and Ordovician rocks.

Lapworth carried his mapping downward into the Uriconian and other volcanic rocks of the Wrekin and Caradoc, and the neighbouring areas, and I believe his large scale maps of these areas are extant. Most of the Shropshire and Montgomeryshire work is summed up in a communication to the Geologists' Association on the occasion of their visit to the region in 1894 (49) and given in fuller detail in the contribution on Shropshire to 'Geology in the Field' (67, 1910).

4.—**The Hyolithes Limestone.**

These discoveries gave renewed interest to the Nuneaton area. When Dr. Stacey Wilson noted the probable existence of calcareous beds and indications of fossils along the junction of the quartzites and shales, this line was thoroughly searched. A new excavation revealed the presence here of a limestone bearing remains of *Hyolithes*, *Coleoloides*, and horny brachiopods. A comparison of these fossils showed that many of them occur in association with *Olenellus* in America and elsewhere. But Lapworth was cautious in correlation, and he stated: *"The exact horizon of the *Hyolithes* zone of the Midlands cannot yet be regarded as absolutely fixed. That it is Lower Cambrian is regarded as more than probable. That it answers to any special part of the *Olenellus* zone has yet to be determined."

In 1898, however, when he wrote his masterly account of the Geology of the Birmingham District, on the occasion of the visit of the Geologists' Association, he and Miss Wood (Dame Ethel Shakespear) reviewed the evidence, and, after comparison with the *Olenellus* and Etcheminian faunas of America and Scandinavia, he was able to go a little further and say: †"The general facies of the curious fauna of this *Hyolithes* Limestone speaks strongly in favour of the view that it is of Lower Cambrian age, answering in part to the *Olenellus* zone of other regions." This view has been subsequently verified by the finding of *Olenellus* in the shales just above the limestone. Mr. Illing also has confirmed and extended Lapworth's conclusions as to the age of the Stockingford Shales, which prove to contain Lower, Middle, and Upper Cambrian faunas, an approximately complete succession.

As his knowledge of the Scottish quartzites had been instrumental in suggesting to him as a working hypothesis that the

* 53, p. 232. † 55, p. 343.

Nuneaton and Lickey quartzites might be much older than had hitherto been supposed, so the occurrence of quartzites followed by 'fucoid beds' at Nuneaton suggested the possibility that the Scottish rocks on this horizon might be of Lower Cambrian age and might bear *Olenellus*. The same view occurred to the Scottish Geological Survey, and was upheld by the discovery of such a fauna there by Mr. MacConnochie in 1891.

Once again, and for the last time, the Geological Survey paid Lapworth the compliment of following his work and testifying to its correctness. In the Nuneaton district they succeeded in finding seven species, including *Dictyonema sociale*, not found by Lapworth, thus raising the known fauna to twenty-one species.* They concluded that the Stockingford Shales " belong to a late Lingula Flag age, including a portion of the Lower Tremadoc Series." The Carboniferous colour on the map was changed to 'Silurian,' and in a later edition to 'Cambrian.' A new edition was also published of the sheet containing the Lickey Hills.

5.—Harlech and the Longmynd.

Two important pieces of work have not so far been published, except in barest outline. They were carried on in occasional leisure intervals after 1890. These are the mapping on the six-inch scale (with portions done on the 25-inch scale) of the Longmynd, which he carried out alone ; and that of the Harlech area, which he did in company with Dr. T. Stacey Wilson. The former area attracted him as the largest rock group below the Cambrian of the Midlands, and on account of its relationship to the Uriconian and Cambrian rocks of Shropshire. His conclusions were outlined in the 'Geology of Shropshire,' published in †'Geology in the Field.' He recognised two Series in the Longmynd itself, apparently not unconformable to one another as supposed by Blake. The higher of the two—the 'Red' or 'Western Longmyndian'—he paralleled with the Torridon Sandstone of Scotland. The lower he suggested to the writer might be the equivalent of the rocks of Charnwood Forest. He also indicated that the Western group of igneous rocks of Uriconian type—the Linley or Pontesford volcanic series—might be separate from and newer than the Cardington volcanic series on the East ; but he never committed himself as to the mutual relationships of the two series, the stratigraphy of which is much complicated by faulting and possibly overfolding.

The general classification and succession of the rocks of the Harlech area were entrusted to Dr. A. R. Andrew for publication in his paper on the Dolgelly Gold Belt.‡ These beds Lapworth

* Geol. Mag., Dec., iii., vol. iii., 1886, pp. 547, 548.
† 67, pp. 748, 749.
‡ Geol. Mag., Dec., v, vol. vii, 1910, p. 161.

and Stacey Wilson regarded as Cambrian, and as conformably underlying beds of known Middle and Upper Cambrian ages.

6.—Other Birmingham Work.

In addition, a number of other areas were mapped, generally in company with advanced students. The following may be mentioned:—Dudley Castle Hill, the Wren's Nest, Rowley, Lilleshall, the Clent Hills.

Lapworth's first connected account of the geology of the Birmingham District (in his interpretation rather a wide area) was contained in the 'Handbook of Birmingham' prepared for the visit of the British Association in 1886—fifty-three pages with a bibliography and map.* This was followed by the paper already referred to (55), published by the Geologists' Association in 1898, which was re-issued as a pamphlet for the use of students in his department. †His last account of the district, practically a third edition, was prepared for the British Association Handbook, Birmingham, 1913—sixty-three pages, with a further bibliography, and physiographic and geological maps on the half-inch scale.

Little was separately published as to research upon the Upper Palæozoic and Mezosoic rocks, and readers may find it difficult to make out from Lapworth's local publications how much is original work. He was specially interested in the Carboniferous rocks, both at the surface and below the Permian and Trias, in the Permian and its breccias, which he regarded as screes, and in the very varied development of the Trias as shown at the surface and in borings. He was keenly alive to the value of all evidence as to the local origin of Bunter materials, and to the importance of any light on the physical conditions under which these and related rocks were formed.

His knowledge of glacial matters, local and otherwise, is shown by his exhaustive review of Crosskey's work,‡ as well as by his own observations made at Birmingham, Wolverhampton, and Church Stretton. Some of his views on local physiography and river development will be gathered from his general treatment of the drainage problems of the 'Black Country'§; while his interesting suggestions on the origin of the present course of the Severn will be found in the Proceedings of the Geologists' Association.‖

We now pass to two sequels to the stratigraphical work, one connected with the organisms in which he was chiefly interested, the other with the larger question of the life history of the Earth itself.

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* 37, 55. † 68.
‡ 52. § 68, pp. 606, 609. ‖ 55, p. 425.

E.—The Graptolites.

Reference has been made above to Lapworth's use of graptolites in his stratigraphical work. It was quite impossible for him to regard these organisms as mere tools or ' hall-marks.' He realised that, as once living creatures, they deserve study from the biological point of view, and that they have their own place in the chain of evolution of life on the earth. When collecting, he always had his eyes open for specimens which might throw additional light on their life history and biological position, and for anything which might indicate their mode of life and the conditions which brought about their distribution, evolution, and eventual disappearance.

His collection became very large, but there was hardly a fossil in it which he could not readily refer to, or of which he could not remember the locality, the horizon, and the circumstances of its collection, even without reference to its label.

He not only made himself thoroughly acquainted with the whole literature of the subject, both British and foreign, and focussed and tabulated the exact state of knowledge of the graptolites themselves, but he made a close study of the living forms which most nearly approach the graptolites in organisation.

1.—Morphology and Classification.

Apart from one (4) on the ' Graptolites of the Gala Group,' 1872, the first paper devoted exclusively to this subject is that ' On an Improved Classification of the Rhabdophora,' 1873, in which was outlined a grouping that has proved the starting point for later researches, with minor modifications, has secured world wide acceptance, and has stood the test of new discoveries, both geological and biological.

The function of the *sicula* as the primitive germ from which the polypary in all graptoloidea is developed is here discovered for the first time. The nature and position of the bud or buds which give rise to the polypary are studied, and the ' angle of divergence ' (sicular or dorsal angle) of branching in bilateral graptolites worked out in relation to the classification of families and genera. The virgula, the shape of the thecæ, and the relation of the latter to the common body are similarly studied. The families, instead of being founded on a single structural peculiarity, are *" constituted by assemblages of species, linked together by a large community of morphological characters, and grouped around typical genera."

In the case of monoprionidian forms the result is regarded by the Author as satisfactory, and their families are so well circumscribed that *" the slightest fragment of the branch of a monoprionidian species can be referred at a glance to its proper family."

* 6, p. 556.

But the author admits that in the case of graptolites with two ranges of thecæ the classification *" although in my opinion the best possible in the actual state of our knowledge, is to be regarded as confessedly temporary and provisional." *" All that is attempted in this department is roughly to prepare the way for the next and future advance in the proper classification of these species." Nevertheless he added certain forecasts as to the probable trend of future research which have been verified in the sequel.

2.—**Graptolite Papers.**

This was followed by a long series of papers, each one of them adding something new :—' Note on the Graptolites discovered by Mr. John Henderson in the Silurian Shales of Habbie's Howe, Pentland Hills,' 1874 ; ' On the Diprionidæ of the Moffat Series,' 1874 ; ' Descriptions of the Graptolites of the Arenig and Llandeilo Rocks of St. Davids ' 1875, with John Hopkinson ; ' On the Scottish Monograptidæ,' 1876 ; ' Silurian Rocks of the West of Scotland ' (with figures of the Graptolites), 1876 ; ' On the Graptolites of County Down,' 1877 ; ' On the Genus *Nemagraptus* of Emmons,' 1880 ; ' On New British Graptolites,' 1880 ; ' On the Cladophora or Dendroid Graptolites collected by Professor Keeping in the Llandovery Rocks of Mid-Wales,' 1880 ; ' On Graptolites,' 1882 ; ' Preliminary Report on some Graptolites from the Lower Palæozoic Rocks on the South Side of the St. Lawrence from Cape Rosier to Tartigo River,' etc., 1886 ; ' Notes on Graptolites from Dease River, B.C.,' 1889 ; and, his last paper, never published in full, ' Balston Expedition to Peru : Report on Graptolites collected by Captain J. A. Douglas,' 1917.

This list of fifteen papers is not only a testimony to his own industrious collecting and investigation, but it shows—quite inadequately, however—something of the help he rendered to his fellow-workers. In many of these cases, and in an abundance of others not separately notified except by acknowledgment in the text of papers by other writers, we learn how much confidence was reposed in his knowledge, judgment, and good nature. He spent much time in determining the forms submitted to him, often describing them if they were new or uncommon, or species important for working out the horizon they indicated, or for showing where further local research was necessary. It is true that on more than one occasion he put a certain strain upon this confidence when he felt bound to assert that the graptolites did not confirm the conclusions to which the field work pointed ; but in each case in which he did this, later research has proved that he and the graptolites were right and the local observer wrong.

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* 6, p. 556.

3.—The Distribution of the Rhabdophora.

I have reserved for separate treatment one of the most illuminating papers ever published, that 'On the Geological Distribution of the Rhabdophora' (18). This, Lapworth tells us, was partly written in 1873 as a sequel to that on Classification (6), but was not published till 1879 in order that he might be able to visit many of the most important graptolite-bearing regions in the country and to study specimens sent to him from South Wales, County Down, and elsewhere, in addition to those of Scotland. From the paper itself it is clear that he visited and studied carefully not less than thirteen of the localities with which he deals, places as far apart as Pomeroy and Shropshire, Llandeilo and Lakeland.

After discussing classification and difficulties, and passing in review the earlier and later history of the subject, the Author under the head of 'Data' deals with the graptolites found in each Formation from the Tremadoc up to the Ludlow, separate zones being recognised where possible or desirable. Then follows a series of range-tables for all known forms to show the distribution of species within each Formation, and a single table for all known genera and species of British Rhabdophora. Next comes an account of each family and genus in relation to its range and peculiarities. Finally there is a list of graptolite zones so far established, and the distribution of graptolite genera within them, closing with an account and a most illuminating table of the distribution of known zones over the British Isles, Europe, and America.

Two important general conclusions formulated in this paper are quoted below:—

*"The host of proofs formerly supposed to be afforded by the abnormalities of the vertical distribution of the Graptolithina, in favour of the doctrine of migration and colonies, vanish into thin air. . . . . We have at present no evidence whatever to show that any single Graptolite group, or even a single species or variety, made its appearance at an earlier date in one region than in another; and, as a consequence, the place of its origin and the direction of its extension in space are at present equally incapable of recognition."

*"All these circumstances conspire to render the Graptolite one of the most suitable of fossils for the purposes of the working geologist and systematist; its short vertical range affording elements for the sub-division of the accepted Lower Palæozoic formations into their component zones; its wide horizontal distribution allowing of the exact parallelism of synchronous deposits

* 18, p. 111 (of separate).

in areas now geographically separated; and its universal dissemination rendering it easy of collection and study."

Even among Lapworth's papers it is difficult to find another which is such a perfect masterpiece of knowledge, research, and presentation; and that is praise indeed. It is not merely a complete vindication of the character of the graptolite as a zone fossil, and a final justification of the author's method of work. It is a thoroughly reliable study of the geological relations of the order, and a store of information mined, refined, and tested to breaking point, of the steel-like links which he forged to bind together the lower palæozoic horizons throughout the world.

4.—The Life of the Graptolites.

By his study of the graptolites in the field and of their nearest living representatives, Lapworth had gradually built up for himself a picture of the living graptolite, its life story, its colonial history, and the conditions and methods which had determined its survival, evolution, and distribution. This he contributed in German, 'Die Lebensweise der Graptolithen,' to a paper by Dr. Johannes Walther, published in the Zeitschrift der deutschen geologischen Gesellschaft in 1897 (54).

The earliest graptolites, the Cladophora, seem to have grown upright, attached to stones and heavy objects on the sea bed. With the incoming of *Dictyonema* and the rest of the Rhabdophora there is attachment by a thread to floating organisms, probably sea-weeds of Sargasso type. In this way the graptolites secured an ocean-wide distribution by currents and winds, and there is explained the presence of their fossil remains in such abundance in deep sea muds, the carbonaceous matter of which is provided by the weeds, and at the same time the reason for the great areas covered by the graptolite zones, and the value of graptolites, exceeding that of any other pelagic organism, as time zone indices. Light is thrown on the biological evolution of the order, on the branching of the colonies, on the gradual simplification, and on the development of the thecæ for obtaining larger supplies of food and better exposure to sun-light.

From this also follows what he often pointed out—the significance of the plenitude of graptolites when their main enemies were no better equipped than trilobites, and their rapid extinction when fishes made their appearance on the scene.

5.—Monograph of British Graptolites (62).

It was only fitting that this work should culminate in the publication of a complete Monograph on the British Graptolites; but the time and facilities for this, though it was often contemplated and preparations were continually being made for it, could

never be found. One of the great difficulties was the illustration of the fossils. Photographs were impracticable, and yet it was most undesirable that the personality of the artist should exercise any influence or bias. Variation in illumination was requisite to ensure that no structure of importance should pass unobserved. A new type of instrument—the Lapworth-Parkes microscope—was devised, and this, under the skilled and artistic workmanship of Miss Wood, solved the most difficult problem.

It was arranged that the Palæontographical Society's Monograph should be edited by Professor Lapworth, that the descriptions should be done by Miss Elles, and in part by Miss Wood, and that the latter should be responsible for the drawings and for writing the critical history of the subject. In this way, year by year, the work was carried on. The eleven parts appeared between 1901 and 1918, and Lapworth had the satisfaction of seeing this part of his life work crowned by a monograph which will rank as the classic work on the subject for many years to come.

One can easily understand the satisfaction with which he must have regarded the great summary table showing the zonal distribution of the British Graptoloidea, dated 1914, which *" may most simply be regarded as the second and greatly extended edition of a combination of Table X . . . . . and Table XI . . . . . as given in the Memoir ' On the Geological Distribution of the Rhabdophora,' 1879-80. *" In the Memoir some twenty Graptolite zones were recognised; that number has now been increased to 36. In the Memoir some 284 species and varieties of British Graptoloidea were referred to; that number has now risen to 372." But if between 1879 and 1914 the work of himself, his students, friends, and imitators, has added but sixteen zones and less than a hundred species in thirty-five years, what are we to think of the work, very largely that of a single man, unaided and ' in opposition,' wrought between 1869 and 1879 ?

F.—The Fold.

It was not till 1892 that Lapworth allowed himself to follow up in wider generalisations the tectonic results to which his study of the works of Rogers, Heim, Suess, Bertrand, and Brögger, and his own observations in regions of highly folded rocks, had led him. In that year he was President of the Geological Section of the British Association at Edinburgh, and gave one of the most striking addresses which has ever been delivered in that Section (48).

After pointing out that two of the life stages of a Geological Formation, detrition and deposition, have been studied in the light of present-day processes, he advocates that the third stage,

* 62, p. 514.

deformation, should be similarly studied. The section across a typical continent and ocean such as America and the Atlantic shows that the unit form of continent is an arch (sagging in the middle) and that of ocean a trough (with a central buckle). These great earth-features are broken into minor waves, the anticlines and synclines of the geologist, of every size and grade, but all composed of arch and trough like the letter S, or Hogarth's 'line of beauty and grace.' Each wave has an arch limb and a trough limb divided by a septum, and the steepest septum, as in a wave at sea, is on the advancing side of the crest. It is this septum which undergoes the greatest amount of twisting and distortion as the fold grows until all three parts are crushed together into a single mass and the fold is dead, but it has given its life to the thickening and strengthening of the weak part of the earth's crust at which it originated. The *" period of greatest effective energy and most rapid movement must be that of middle life," when the septum is vertical.

1.—Geographical Relations.

Applying these deductions to earth features, the steeper, or ocean, septa of the great North American folds show greater crumpling and metamorphism than do those on the Mississippi sides. Of the two folds, that on the Pacific side has a steeper septum than that on the Atlantic side, it is 'ablaze with volcanoes, or creeping with earthquakes,'† and has in front of it the great Pacific 'deep.' Similarly in the central buckle of the Atlantic trough the volcanic islands are septal in position.

A like feature on a still grander scale is the 'land hemisphere' with its 'central sag,' the Atlantic, opposite to which is the great trough of the Pacific Ocean with its median buckle the foundation of the oceanic islands of the central Pacific. Since this fold is endless and returns upon itself—its septum must likewise be endless; it is the 'Volcanic Girdle of the Pacific,' the 'Terrestrial Ring of Fire.'

Thus the ‡" wave-like surface of the earth of the present day reflects . . . . the wave-like arrangement of the geological formations below." " The physiognomy of the face of our globe is an unerring index of the solid personality beneath."

But as the result of other tangential stresses §" the simple fold becomes a folded fold, and the compound septum twists not only vertically but laterally." It is this which accounts for domes and basins, for the sweep of island festoons, and §" for the detailed disposition of our lands and our waters, for our present coastal forms, for the direction, length, and disposition of our mountain

* 48, p. 703. † 48, p. 704. ‡ 48, p. 705. § 48, p. 706.

ranges, our seas, our plains, and lakes." The stresses *" account also for the formation of laccolites, of granite cores, and of petrological provinces ; and they enable us also to understand many of the more striking phenomena of metamorphism." †" The surface of the earth of the present day seems to stand midway in its structure and appearance between that of the sun and that of the moon, its eddies wanting the mobility of those of the one and the symmetry of those of the other."

‡" Thus from the microscopic septa of the laminæ of the geological formations we pass outwards *in fact* to those moving septa of our globe, marked on the land by our new mountain-chains, and on our shores by our active volcanoes. Thence we sweep, *in imagination*, to the fiery eddies of the sun, and thence to the glowing swirls of the nebulæ ; and so outwards and upwards to that most glorious septum of all the visible creation, the radiant ring of the Milky Way."

These subjects he pursued farther in an address to the Royal Geographical Society on ' The Face of the Earth,' parts of which were fortunately reported in *Nature*. § Here it is pointed out that the continents are merely the undrowned parts of the submarine continental plateaux, which are the crests of the folds and stand antilogous to the ocean troughs, on which again the deeps correspond to the unsubmerged continents. The dividing line comes midway down the submarine slope from 1,000 to 2,000 fathoms below sea level, the septum of the fold. As might be expected from the fold theory, calculation has shown that the area of the earth's surface on the continental side of this line is equal to the area on the oceanic side of it ; while the volume of water below its level is equal to the volume of land above it.

Lapworth showed, too, that as there are three meridional crests stretching from pole to pole, America, Europe-Africa, and Asia-Australia, with three corresponding oceanic troughs, so there are three longitudinal crests met in passing from N. to S., viz., North America, South America, and the Antarctic Continent (the existence of which he incidentally predicted on theoretical grounds).

Then he indicated and illustrated by diagrams that the interference of these sets of folds accounts for §" (1) the form and disposition of the terrestrial continents ; (2) the triangular shapes of their extremities ; (3) the diagonal trends of their shores ; and (4) the courses of the archipelagic lines." He dealt with the interference and superposition of waves, the rhythmic repetition of forms of lower order, possessing in miniature the characters of major forms, and on this principle contrasted the straight and simple West American wave and its deep, with the complex Alpine range

* 48, p. 707. † 48, p. 706. ‡ 48, p. 707. § 50.

and its compound Mediterranean depression. Finally, he pointed out that denudation and deposition were located by, and subordinated to, the actuating position of the dominant folds.

He returned once again to the physics of the fold in his Presidential Address to the Geological Society in 1903, where he sums up his view of deformation as follows:—Its type *" may be that of undulation, warping, folding, gliding, fracture, or flow, according as the magnitude of the stress, the speed of the action, or the relative elasticity of the material may determine; its development may range in time from that of an instant to that of an æon; and its extent from microscopic to hemispheric."

2.—Time Relations.

In the address on 'The Face of the Earth,' Lapworth made a brief allusion to the time-relation of folding as a key to †" the cycles, systems and transgressions of the geological formations." This idea he developed more fully in a communication to the Geologists' Association on 'The Relief of the Globe,' in June, 1894, which was never published. In this address, among other matters, he showed how the succession of events revealed by the geological Systems might be connected with the passage of waves each consisting of a sagging arch and a buckled trough over the site of the British Isles, thus connecting, as he loved to do, the events of the past with the physiography of the present.

3.—The Dolomites.

It may be mentioned that at the Edinburgh meeting (1892) of the British Association at which Baron von Richthofen, the author of the coral reef theory of the rock-masses of the Dolomites, was present, he took the opportunity to expound the views to which he had been led by the study of the literature of that region. He had concluded that the remarkable and sudden local thickening of the limestones was probably to be explained by folding and earth movement, a view which has been entirely justified by the work of Miss Ogilvie (Mrs. Ogilvie Gordon). ‡

G.—Economic and Advisory Work.

Many phases of Lapworth's work show his voracity for exact knowledge, which rarely left him satisfied until he had studied the facts and sections for himself in the field. In nothing is this more true than in his work on economic and expert lines; and indeed

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* 63, p. 81. † 50, p. 617.

‡ Quart. Journ. Geol. Soc., vol. xlix. (1893), pp. 1-78; id. vol. lv. (1899), pp. 560-634.

one is driven to the conclusion that his main inducement to undertake such work was that it gave him access to facts otherwise unattainable.

This work was chiefly concerned with coal-mining, with foundations, and with water-supply both over and under ground. He took keen interest in it, not only on its geological side but in the problems of engineering, transport, and industry involved. His knowledge of the South Staffordshire and Warwickshire Coalfields became very complete as regards the floor on which they rest, the red-rock cover, and the constitution and variation of the Measures themselves. There were few of the more critical and experimental enterprises, where the problem was complicated by faulting or unconformity, which did not have the advantage of his guidance, and he secured not a few triumphs by his accurate predictions, or by his cautious advice. It was in the course of this work that he began collecting information for a contour map of the 'Thick Coal'—work taken up later and brought to a successful issue by his friend, Mr. Wickham King.

1.—The Midland Coalfields.

This extensive knowledge proved of exceptional value to the Second Coal Commission (1902-1905), of which he was a member. He took a very active part in the whole enquiry, undertaking more especially the details of the central group of coalfields (district "B"), and writing a lucid and masterly account of the interrelations of these fields and their probable continuation as 'concealed coalfields' in the areas intervening between them. His description of the area given in the Commission's Report* was put into graphic form and dealt with in very lucid fashion in a paper to the Institution of Mining Engineers.†

The area is bounded east and west by the Shropshire and the Leicestershire 'platforms,' the latter mainly buried, the former better exposed. Between them lies the anticline of the South Staffordshire Coalfield with the Birmingham Basin on one side of it and the Wolverhampton Basin on the other. To the northward lies the Staffordshire Basin dividing the South Staffordshire Coalfield from the southern end of the Pennine Chain. The parts of these Basins which may be regarded as 'proved' are marked off, and then the likelihood or otherwise, of the extension of Coal Measures in the residual areas is worked out and calculated. All existing evidence on the behaviour of the Coal Measures themselves, especially in relation to their conditions of formation, the character of the floor in which they were formed, the nature and thickness of the red-rock cover, and the folding, fracture, and other accidents

* 64. † 66, pp. 26—50.

which they have suffered, is considered and is assigned due weight. Lapworth's general conclusions are that the Coal Measures originally covered 11,000 square miles in the area he is considering. From 3,000 square miles they are known to have been denuded; 1,700 square miles are exposed at the surface, 800 are buried but have been tested or worked. Of the remaining 5,500 square miles, probably more than half will be eventually reached and worked within 4,000 feet of the surface of the ground.

His work on foundations, borings, and water-supply is equally sound, and is based as firmly on scientific principles, but naturally very little of that is available for description. We may, however, refer to a short paper on Underground Water-Supply in relation to Brewing,* to his lectures on water, and to the work he did for the Birmingham Corporation, for the South Staffordshire Waterworks Company, and for Harrogate, Gloucester, Leicester, and many Midland towns.

2.—The Geological Survey.

The national work done by Lapworth in relation to Coal Supply finds its parallel in his services on the Departmental Committee which considered the position and work of the Geological Survey, as a result of which it was decided to modify and extend the work of that body. For the Committee's Report he wrote an account of the 'Uses of Geology and the Geological Survey,' in which he brought out in a popular and easily understood form the immense importance to the country and the Empire of a thorough knowledge of the mineral resources on which their wealth and prosperity are dependent. The most is made of the industrial progress of the United States and Germany, and the relation of so much of this to the mineral wealth of those countries and to the knowledge of it which has been acquired and published either officially or unofficially. But here, as so often elsewhere, he insists that †"survey work—whatever its economic applications may be—is in origin and spirit scientific." ‡"The first and foremost duty of the geological surveyor is to map the country, and to map as correctly as may be up to the standard of the time, prompted less by the desire for scientific discovery than by the desire for scientific accuracy." He is confident that if only this duty be conscientiously discharged there need be no doubt that economic results of high value will inevitably follow.

H.—Teaching Work.

1.—Students.

In dealing with Lapworth's teaching work, first place must be given to his College lectures, both those given to his regular

* 60. † 59, p. 13. ‡ 59, p. 14.

students in geology, mining, or engineering, and those delivered to more popular audiences at afternoon or evening classes. The first group were very systematic and comprehensive, and in addition to covering the ordinary routine work they gave special attention to economic work and to the fitting of students to take part in geological investigation. The economic geology classes were instinct with reality, and the students, many of whom, though trained as engineers or mining men, have found opportunities for geological investigation, felt that their teacher was intimately acquainted, as indeed he was, from personal work, with the tectonics of the Midlands and its bearing on the winning of the coal-seams and on the water supplies of the area. They were shown the relation of geological structure and outcrop to the location of industries and habitation, and the bearing of the natural distribution of mineral resources on history, economics, and agriculture. A new departure was made in teaching advanced students what he called 'Structural Geology,' in preparation for field-mapping. This work was very thorough, an attempt being made by Lapworth to give to his students some of his own unequalled power of understanding and visualising the geometry of underground structures. Each class was followed up by a field day in some selected area—Dudley in one year, Rowley, Nuneaton, or elsewhere in another, when each student was trained in making geological observations, recording them in his map and notebook, and afterwards, partly in class and partly independently, in working out a completed six-inch map of the selected area. One of the things which gave Lapworth the greater pleasure in his local discoveries was his delight in seeing his students discover them anew (generally with his judicious suggestion or prompting), and one might almost think that this furnishes a reason in some cases for lack of haste in publication.

The 'popular' classes for the most part took some of the simpler branches of geology or geography or something which combined the two things; but in some years more difficult subjects, such as problems of geophysics or geomorphology or tectonics were tackled, illuminated by wide reading and personal observation, and yet made sufficiently simple for the audience to follow if they were prepared for a certain amount of intellectual effort.

All these lectures, whether regular or occasional, were carefully prepared and well thought out, but it was no uncommon thing for the Professor to strike some new vein of thought in the course of the lecture itself, and then he would lay aside his notes and plunge into the discussion and illustration of the new problem in all its intricate bearings. Thus his students were not only impressed with the living and dynamic aspect of the science he taught, and with its rapid and continuous growth, but they felt themselves

in the presence of a thinker and discoverer and carried away some of the sacred fire which inspired him. One of his former students writes :—

"Lapworth's lectures were unlike any others that I have ever heard, and many of his students felt strongly the inspiration of the man. In particular I recall a lecture of his on the Silurian System. It was indeed a revelation, for the veil of the past was drawn aside and the sequence of geological events was disclosed in a series of pictures of a vividness so intense that the hearers forgot that they were merely listening to words; they *saw* the sinking of the coast lines, the deposition of the sediments, the floating weed-borne graptolites, the clearing of the waters as the sea vanquished the land, the marvellous growth of corals,—as if the speaker were a painter who had been present through the ages and could show the pictures he had painted and say 'thus and no otherwise it was.' For, in truth, although he gave with scientific precision the evidence for his statements, the words were the words of a poet or an inspired prophet speaking forth the things which he had seen. And then, at the end of the lecture, some characteristically humorous remark, accompanied by a twinkle of his piercing eyes, would suddenly relieve the strain, and with something of a shock we realised the warm humanity of the prophet. The aeroplane had come to earth and the pilot was turning round and smiling at us!"

What is true of the lectures is still more true of the excursions, when he was not afraid to 'let himself go' in the presence of the facts, by which he could be tested but of which he always knew so much more than he felt it necessary to tell. Very few men have ever been able so well as he to visualise the structure of the country when viewed from some commanding point, and to lay it before his hearers so that they too seemed to see the rock-framework under the landscape and the vegetation. He was full of apt analogies, most happy in crisp and adhesive nomenclature, quick to see difficulties or possibilities of confusion, and ready in illustrations, often drawn in the dust with an umbrella, scratched with a knife on a shard of shale, or modelled on the grass with sticks and stones. And always there was just the glimpse of something beyond, towards which the case under consideration was tending but perhaps did not quite prove, sustaining the interest and 'carrying on' to the next observations. Professor J. E. Marr, in his 'appreciation' in the Geological Magazine, says* "he would explain the structure of the surrounding country during the frequent intervals between the relighting of his pipe, until its aspects during the different geological periods seemed to glow before the hearer's vision."

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* Geol. Mag., vol. lvii, 1920, p. 197.

2.—**Text Books.**

It is hardly to be expected that much of an author's personality should permeate his textbooks, but here we have an exception. Into his editions of Page's introductory textbooks on Physical Geography and Geology, Lapworth brought much new material, but in the case of the latter work he freed himself from the shackles of the old edition when he issued his own 'Intermediate Textbook of Geology.' The main feature of this book is not only its grasp of principles but the wonderful way in which the stratigraphical and historical portion, usually a heterogeneous mass of unrelated facts, falls into an ordered whole, the picture of each System being clear and bright, and the history included in it, both at home and abroad, being vividly told, and brought out in marked individuality and clear relation to events before and after.

3.—**Old Students and others.**

But it is not to lectures or books only that we must look for the effect of Lapworth's influence as a great teacher. His work was so well known, his judgment and sympathy so highly prized, his genius so much respected, that old students, scientific friends, and workers in geology constantly sought his help, advice, and encouragement. He was one of those rare men who have the faculty not only of projecting themselves into the interests and dreams of their friends, but also the marvellous knack of drawing out their best from them, of inducing them to reveal their inmost thoughts, and of learning by alluring questions what they know and believe, and the grounds of their knowledge and belief.

He was himself so full of ideas and so generous in imparting them, while at the same time he was so eager to hear of new work and to gauge its value, and so deeply interested in all branches of his subject, that he made a most delightful confidant, and his visitors were assured of his sympathy and patience. He hoped always to acquire new information or new light on old information which would react on the observations of himself or others. What he gained for his own work in this way was insignificant in comparison with what he gave back to his interlocutor in the form of suggestion or theory, sympathy and encouragement. No man was ever so lavish in original ideas, the most precious possession of a scientific worker, or so generous and trustful in planting them where he thought or hoped they would bear fruit. His ideas and suggestions have fertilised the research of a whole generation of geologists, not only in this country but abroad. When presenting the Wollaston Medal in 1899, Mr. Whitaker, then President of the Geological Society, referred to *" the highest of all teaching, the

* Quart. Journ. Geol. Soc., vol. lv, 1899, p. 40.

influence that you have had on your fellow-workers in Geology. That influence is to be traced in much of the work that we have had of late years, and during our present session we have had papers which, I venture to say, would not have been written but for lines of thought suggested by you."

A fund was raised by Lapworth's Midland friends and others interested in geology, in order to provide for assistance in some of his routine work and to give him more time for research. The fund proved sufficient for this purpose, and as well it provided some addition to the cramped space previously occupied by the Geological Department of the University. Through the operation of the fund Lapworth was able to carry out several researches for which it would have been impossible otherwise to find time, including in particular the Graptolite Monograph, to the editing of which he gave very close attention.

I.—Conclusion.

On reviewing the life and work of Professor Lapworth, it is impossible to avoid being struck by the salient features of his character and equipment.

The leading characteristic was his intense mental and bodily energy, which were so great that they more than once overtaxed his powers. With this was coupled a burning enthusiasm, which never allowed him to shirk trouble in acquiring a fact or devising an explanation ; a living belief in the value of research ; trust, founded on experience, that problems could be solved ; intense faith in his own science, and a love of it which glowed in many of his utterances.

His great driving force was derived from two things ; his overmastering love of truth, and his delight in overcoming obstacles.

Truth was to him a veritable religion, the one great object that it is in the power of man to compass if his will be but strong enough. The mainspring of his research was to widen the bounds of knowledge, true and tested. For honours or advancement he cared little, except in so far as they enlarged his opportunities or benefited the science he loved. Nothing short of exact and exhaustive knowledge satisfied him, and that is why his work requires so little revision and is so difficult of extension. But as he grew older and realised how much confidence was placed in his lightest word by those who knew and trusted him, he grew slower and increasingly cautious in publication.

With this love of truth was naturally linked distrust in assumption of authority, unless founded upon a solid basis of well-proved fact. He fought strenuously against any attempt to strangle enquiry by authority, to shackle truth by convention, or

to cripple advance by rules of nomenclature. At the International Geological Congress of 1888* he warned the members that no rules must be drawn up or systems imposed, which would hamper investigation or impede advance. On another occasion he penned the following incisive words :—†" The subject [geology] is perfectly free and open to all. Every investigator has a right to address himself to any part of the work he pleases, and the right, if he deems it fitting to exercise it, to demand a full recognition of the importance of his own contribution to the common stock of discovery. No investigator, or body of investigators, has any claim, beyond that conceded by courtesy, to a monopoly in any special department of geology, local or theoretical. The only available geological possessions of the investigator are his abilities, his opportunities, and the fruit of the good work he has done in the past. The only authority he dare recognise with safety is Nature herself. The extremest penalty for the slightest departure from the course she has marked out, whether committed wilfully or in ignorance, will be mercilessly exacted by her tardy but sure-footed avenger—Time."

In the search for truth he realised that the truest things we have are the principles of science. To these he pinned his faith as soon as he had satisfied himself that they were well proved, and he was always willing to devote time and energy to the testing of the basis of every fact or inference which seemed to him to run counter to well-established principles. At the same time he was more than willing to submit his own hypotheses, as well as those of others, to the crucial test of observation and experiment, and if necessary to modify them or to suspend judgment until proof was forthcoming.

His hope and aim were always the establishment of new and true principles. He held that every effort should be made to group facts together, provided that the resulting hypothesis were regarded as one ‡" not of causes but of the most natural grouping of effects." One theory after another would be tested and re-tested against the facts, only to be rejected and replaced if necessary by one in better accord.

It was here that his wonderful imagination, vivid but disciplined, came into play. His interest in the structure of the earth crust was not in the anatomy of a structure, beautiful and complex but dead. It was that of a biologist in a living organism, changing and growing, resting or moving, with a long history, of which he could vividly visualise each stage. Like a physiologist, he constantly strove to understand the source of the life energy of the globe and the exact mechanism which has guided the formation and distribution of its features, and the changing life of and on its surface.

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* 43, p. 223. † 33, p. 102. ‡ 50, p. 617.

From the sequence of Lapworth's papers on the Southern Uplands and on the Graptolites, it is evident that his energy and power of work redoubled when he saw that he was up against a really serious problem. In each of his greater pieces of work we realise that one of the chief attractions was the difficulty of getting a solution, and in many cases we are able to see the stages by which he worked and thought out the several steps of it.

His instinct for crucial tests was a great gift, carefully nurtured. After reading up a subject in which he was interested he could readily see the lines on which it was best to attack the problems involved, the places where the sections would be most critical, or which of the consequences of a theory were the simplest to test and the most likely to yield an unequivocal answer.

The same instinct led him to vary the direction of attack whenever he met with repulse or could not get a definite reply. His papers do not tell us how often he met with preliminary difficulties ; we only see that at last he succeeded, and then he takes us first to the most critical and illuminating places, and, by the use of the evidence there, he lightens our difficulties when we come to those which give less decisive evidence.

It was this elasticity of attack which so much impressed the great French geologist, Marcel Bartrand, and led him to write in 1892 as follows :—

*" Peu de carrières géologiques offrent l'exemple de succès comparable à ceux de M. Lapworth. Dans le sud de l'Ecosse, c'est à l'aide des graptolithes, organismes inférieures, dont la valeur paléontologique pouvait sembler contestable, qu'il a établi des horizons dans un série qui avait défié tous les efforts, et les zones établiés dans le petit coin de Dobbs Linn se rétrouvent maintenant dans toute l'Europe et jusque dans l'Amérique. Pour le nord de l'Ecosse, c'est avec des données moindres encore, avec des traces de vers, avec des différences lithologiques de couleur et de grain, qu'il a fixé ses horizons, qui, là encore, se sont trouvés d'une constance et d'une extension inattendues. A l'aide de ces outils qu'il a forgés lui même et que d'autres eussent dédaignés, il a donné la clef de la géologie de deux grandes provinces de l'Ecosse."

Courage and resource in attack were accompanied by patience and courage of endurance. He could wait years, and had to do so, for the recognition of the value of his Upland and Highland work, and longer still for the application of it to bear the fruit which he knew it was capable of yielding. But when his ideas had been perforce accepted and his methods adopted there was the courage of restraint in success.

* Revue génerale des Sciences pures et Appliquées, No. 23 (Dec., 1892), p. 9 (of separate).

It was the same courage which enabled him to deduce to the full the logical consequences of his discoveries, and to use these again as weapons for attacking the next problem and making the next advance. But he never allowed this quality to tempt him into premature speculation; and it has been found that many things either offered by him as hypotheses in his own work or suggested to his students or co-workers, were in reality already based on a deep substratum of fact stored up in his own memory, though not necessarily stated or published.

It seems needless to refer to Lapworth's intense joy in the open air and the love of beautiful scenery which not only led him into the open but to some extent directed his choice to the Ordovician rocks and to those more ancient still. Combined with this was a genuine delight in the work of mapping in which he was willing to spend every hour of leisure he could snatch from his professional duties.

Lapworth was richly endowed with the mental faculties which are most needed by a successful geologist. First and foremost comes the faculty of observation, a keen eye for a country, a power to see through the surface by means of the surface, a genius for spotting where a fossil may be found, a skilled hand in the extraction of it, and sufficient industry and interest to search exhaustively. Then comes the exact and retentive memory which was always ready for service and very rarely played him false; a memory for lithological types or palæontological characters, for crucial places and minute features observed or half-observed in exposures. This was combined with a critical power of discrimination which showed itself in his judgment of things as well as of men.

He was a remarkably good geometrician with the faculty of 'seeing solid' whether into a map or into the ground it portrayed. In working over his own field maps he was never satisfied until he had obtained a workable geometrical solution in accordance with all the facts. The same faculty was of great use to him in judging the value of the work of others when expressed on maps.

The hand of a skilled draughtsman was no small part of his equipment, as must be admitted by all who have examined his maps. His lines are never 'wooden' or awkward, or unnatural, but always artistic and beautiful, as they must be in nature. It is almost impossible to imagine any workmanship more perfect than his drawings of graptolites, or the sections and drawings with which he illustrated his Upland work, particularly in the Moffat paper. The faithfulness and delicacy of his line would have done credit to Du Maurier himself.

The mental power which he possessed had been carefully trained and cultured by himself. He had a good knowledge of languages, exceptionally wide reading, a nice judgment in literature, and a cultivated taste in art and music. He had a remarkable power of visualising and mapping out mentally the things and places of which he read. Few men have better possessed the faculty of tearing the heart out of the literature of a subject. When he started an investigation he went into it armed with a thorough knowledge of all that had been said and written, and with a critical appreciation of the value of each part of it.

He acquired the gift of clear and incisive writing, and a style which appeared easy and free, though it was often the result of laborious correction and revision. He held that scientific writing should be as clear as scientific thinking, and that it was the duty of a writer both to speak unequivocally and to spend his own time rather than that of his reader.

His historical knowledge was a part of his scientific equipment, and he delighted in showing how often old principles and even exploded theories were to be found dominating modern thought. How the ideas of the Schools of Werner and Hutton still produced cleavages in geological opinion; how Murchison starting out to break up the 'Transition Greywacke' into subdivisions gradually reverted to the tendency to reunite them all again into a single system; how catastrophism had not yet been eliminated from our views and methods of classification; or how the work of Lyell had made possible the theories of Darwin.

Finally we have to note the tact with which he unvaryingly handled difficult matters of scientific controversy. Right through his writings and his public career, his maxim was to conceal the iron hand in the velvet glove, to be yielding but firm, to get what he knew to be the greatest good with the minimum of friction and resistance.

It is as difficult a task to portray the complex and beautiful character of the man we are considering as it has been to attempt an expression of the genius which inspired his labour. It must suffice to quote what he himself wrote of his friend and contemporary, Linnarsson, in 1882.

*"His intense scientific ardour gave his body but little real rest. His mind and pen were never idle, and at the least sign of renewed health he hurried to the field of his duties again. Absorbed in the keen delights of his original research, rewarded, as it always was, with almost instant and brilliant discovery, Linnarsson seems never to have adequately realised the deadly nature of his disease. His enthusiastic mind overbore and overtasked the weakly frame,

* 27, p. 3.

and in the keen ardour of the scientific chase the proper precautions for the bodily rest and refreshment seem to have been often overlooked and forgotten. When we recollect the disheartening and prostrating effect of these repeated attacks of illness . . . . . the remarkable scientific successes he achieved during the last ten years, and the vast amount of intellectual labour he must have accomplished, appear little short of miraculous."

And again—

*" In such a region no one could hope for success but he who possessed an eye trained to recognise the most minute distinctions in petrological and palæontological characters in the field, a memory gifted to retain them, a power of generalisation sufficient to group them at once in their natural relationships, a faith in his own judgment enough to follow the conclusions they indicated to their widest issues, and above all an intense delight in the labour itself. Linnarsson, pre-eminent among his contemporaries, seems to have possessed all these qualifications, and his success was proportionately great."

If in these sentences we substitute the name of the writer for the subject, Lapworth for Linnarsson, we have such a picture of the man as few could have written and fewer still could have had the right or authority to pen. Quoting once more from Professor Marr's "appreciation"—†" We claim Lapworth as one of the foremost geologists of all time. . . . . We have lost a great geologist and withal a man of very beautiful character."

[The writer desires to express his gratitude to Sir Jethro Teall, Professor J. E. Marr, Dame Ethel Shakespear, Professor Fearnsides, and Mr. Lamplugh, who have most kindly looked over his manuscript, and made valuable suggestions; and to that old student who has so vivid a memory of a certain Silurian lecture.]

* 27, p. 5. † Geol. Mag., vol. lvii, 1920, p. 197.

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